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Analysing Queuing Systems in Convenience Store Using Queuing Models

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Abstract

This study applied queueing theory to analyze customer waiting times and service times in two convenience stores in Terengganu to understand server utilization during peak and non-peak hours. Both convenience stores were located in areas surrounded by residential neighborhoods, schools, and office districts such as post offices, clinics, and markets. The main factors studied were customer arrival rates, service rates, waiting time in the queue, and server utilization. These factors were analyzed using queueing models such as M/M/1 and M/M/c. Python was used to analyze the data that was collected through observation. The results showed that during peak hours, the number of customers was higher for both single-server and multi-server systems. This caused higher server utilization and longer waiting times. During non-peak hours, fewer customers arrived, which resulted in shorter queues and faster service.

1. Introduction

The definition of self-service retail is to allow customers to choose products by themselves and only contact employees when paying at the counter, which is the usual practice of convenience stores. Under this system, customer satisfaction depends on store layout, cleanliness, responsiveness of staff, efficiency at checkout, and waiting time. Its theoretical basis is that a high level of customer satisfaction will minimize customer complaints, dissatisfaction, and service recovery costs [1]. Customer satisfaction is defined as an evaluation that is made after the consumption experience, depending on whether or not customer needs and expectations are met or exceeded [2]. Consequently, the concept of customer satisfaction has evolved to become one of the most important strategic concerns for organizations, even though the dimensions of the concept of service quality may differ from one organization to another [3].

It is important to take into consideration the lengthy waiting times, especially at peak hours, which will dissatisfy customers and eventually result in lost sales. Faster checkout processes could help decrease congestion, as could proper staffing of cashiers and the use of self-service systems or digital methods of payment to help alleviate congestion and enhance the shopping experience in general [4]. It is also important for efficient service management in a way that increases customer satisfaction while managing operating costs, since inefficient resource utilization reduces actual service performance [5]. Effective service efficiency enables balancing cost control and customer satisfaction for sustainable business growth.

Previous studies on queuing theory mainly focused on fast-food restaurants and were limited in location and time scope [6]. In contrast, this study focused on convenience stores and compares service performance during peak and non-peak hours at different locations. This study applied queuing theory, first proposed by A.K. Erlang in the early 20th century, to study congestion in telephone systems [7]. Using M/M/1 (single-server) and M/M/c (multi-server) queuing models, this study systematically evaluates service efficiency, waiting time, queue length, and server utilization to help convenience store management improve service quality in a simple and efficient way.

2. Methodology

This study utilized queue theory to determine the waiting time of customers in two convenience stores in Terengganu. The study observed the waiting time of the customers during both peak and non-peak hours. The data collection for the study was conducted over ten days for both stores. Queue theory utilizes the single-server and multi-server queueing models. Python programming helped in the data analysis. Python programming is a popular technique for calculating the main design parameters like the average waiting time of the queue, the average waiting time in the system, and server utilization. Python programming helped in processing large volumes of data with fewer errors. The study utilized queue theory to determine the waiting time of the customers in the two stores. The single-server model (M/M/1) involved one service counter serving one customer at a time. It was used to measure arrival rate, service rate, waiting time, and server utilization. This model is suitable for places with only one counter. The multi-server model (M/M/c) involved several service counters serving customers at the same time. This model was suitable for stores with high customer arrivals, as it helped reduce waiting time during peak hours.

2.1 Data Collection

The data was collected by observing customers at two convenience stores at Terengganu. Customer arrival time, waiting time, and the number of customers during peak and non-peak hours were recorded. Peak hour was from 12 pm to 2 pm, while non-peak hour was from 10 am to 12 pm for Convenience store 1 and from 4 pm to 6 pm for Convenience store 2. The observation was conducted from Sunday to Thursday because these days usually had more customers. The assumption is that both systems follow the first-come-first-served rule so that the customers are served on a first-come-first-served basis as per the FCFS rule [8]. This data was used to compare customer flow and service efficiency during peak and non-peak hours.

3. Equations

3.1 Equations of Single Server Model M/M/1

The arrival and service time are exponentially distributed in the M/M/1 queuing model (Poisson process) [9]. The following factors will be explored for the counter M/M/1 queuing model analysis, where λ is the customer arrival rate, and μ is the service rate.

Server utilization, ρ

$$\rho = \frac{\lambda}{\mu} \tag{1}$$

Expected number of customers, L_s

$$L_s = \frac{\rho}{1-\rho} \tag{2}$$

Average number of customers waiting in queue, L_q

$$L_q = \frac{\rho^2}{1-\rho} \tag{3}$$

Average time a customer spends in waiting line waiting for the service, W_q

$$W_q = \frac{\rho}{\mu-\lambda} \tag{4}$$

Average number of customers spends in the system (in waiting line and being served), W_s

$$W_s = \frac{1}{\mu-\lambda} \tag{5}$$

3.2 Equations of Multi-Server Model M/M/c

The following formulas represent the multi-server queuing model analysis, where λ is the customer arrival rate, and μ is the service rate.

Utilization factor, ρ

$$\rho = \frac{\lambda}{\mu} \tag{6}$$

Probability of no customers, P_0

$$p_0 = \left[\sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!} \left(\frac{1}{1 - \frac{\rho}{c}} \right) \right]^{-1}, \frac{\rho}{c} < 1 \tag{7}$$

Expected number of customers, L_s

$$L_s = L_q + \rho \tag{8}$$

Average number of customers waiting in queue, L_q

$$L_q = \frac{\rho^{c+1}}{(c-1)!(c-\rho)^2} p_0 \tag{9}$$

Average waiting time in system, W_s

$$W_s = \frac{L_s}{\lambda} \tag{10}$$

Average waiting time in queue, W_q

$$W_q = \frac{L_q}{\lambda} \tag{11}$$

4. Result and Discussion

The data was collected within 2 weeks at Convenience store 1 and Convenience store 2 in Terengganu during peak hours and non-peak hours. The observations are conducted from Sunday to Thursday, covering weekdays.

Table 1 Collected data from Convenience store 1 during peak hour

Date	Day	Number of Customers (Person			Number of customer being served
		12.00 pm-1.00 pm	1.00 pm-2.00 pm	Total	
1-Sep	Mon	23	16	39	21
2-Sep	Tue	20	28	48	24
3-Sep	Wed	23	24	47	23
4-Sep	Thu	21	23	44	20
7-Sep	Sun	14	28	42	28
8-Sep	Mon	16	21	37	19
9-Sep	Tue	17	23	40	20
10-Sep	Wed	24	19	43	21
11-Sep	Thu	20	24	44	22
14-Sep	Sun	19	23	42	21

Table 1 showed the number of customers recorded at Convenience Store 1 during peak hours from 12.00 pm to 2.00 pm. The data was collected over ten days. The total number of customers varied each day, with the highest number recorded on Tuesday, 2 September, with 48 customers. The number of customers being served ranged between 19 and 28. This data shows that customer arrivals were higher during peak hours, which affects waiting time and service performance at the store.

Table 2 Collected data from Convenience store 1 during non-peak hour

Date	Day	Number of Customers (Person			Number of customers being served
		10.00 am-11.00 am	11.00 am - 12.00 pm	Total	
20-Oct	Mon	18	15	33	19
21-Oct	Tue	13	13	26	16
22-Oct	Wed	19	15	34	20
23-Oct	Thu	12	20	32	18
27-Oct	Mon	16	21	37	17
28-Oct	Tue	13	16	29	17
29-Oct	Wed	14	15	29	16
3-Nov	Mon	12	17	29	16
6-Nov	Thu	13	20	33	19
10-Nov	Mon	20	17	37	19

Table 2 showed the number of customers recorded at Convenience Store 1 during non-peak hours from 10.00 am to 12.00 pm. The data was collected over ten days. The total number of customers per day ranged from 26 to 37 customers. The highest number of customers was recorded on 27 October and 10 November, with 37 customers each. The number of customers being served ranged between 16 and 20. Overall, customer arrivals during non-peak hours were lower and more stable compared to peak hours, resulting in smoother service at the store.

Table 3 Collected data from Convenience store 2 during peak hour

Date	Day	Number of Customers (Person			Number of customers being served
		12.00 pm-1.00 pm	1.00 pm-2.00 pm	Total	
3-Aug	Sun	56	59	115	95
4-Aug	Mon	63	62	125	96
5-Aug	Tue	41	51	92	80
6-Aug	Wed	48	38	86	61
7-Aug	Thu	58	49	107	76
10-Aug	Sun	56	47	103	77
11-Aug	Mon	57	48	105	76
12-Aug	Tue	62	57	119	95
13-Aug	Wed	60	59	119	89
14-Aug	Thu	56	50	106	79

Table 3 showed the number of customers recorded at Convenience Store 2 during peak hours from 12.00 pm to 2.00 pm. The data was collected over ten days. The total number of customers per day ranged from 86 to 125 customers. The highest number of customers was recorded on Monday, 4 August, with 125 customers. The number of customers being served ranged between 61 and 96. This shows that Convenience Store 2 experienced very high customer arrivals during peak hours, which led to longer waiting times and higher server utilization.

Table 4 Collected data from Convenience store 2 during non-peak hour

Date	Day	Number of Customers (Person			Number of customers being served
		4.00 pm-5.00 pm	5.00 pm-6.00 pm	Total	
28-Sep	Sun	36	27	63	28
29-Sep	Mon	33	33	66	31
30-Sep	Tue	30	36	66	29
1-Oct	Wed	39	35	74	33
2-Oct	Thu	30	37	67	31
6-Oct	Mon	32	36	68	31
7-Oct	Tue	33	42	75	32
13-Oct	Mon	28	45	73	33
14-Oct	Tue	32	37	69	32
6-Nov	Thu	33	36	69	30

Table 4 showed the number of customers recorded at Convenience Store 2 during non-peak hours from 4.00 pm to 6.00 pm. The data was collected over ten days. The total number of customers per day ranged from 63 to 75 customers. The highest number of customers was recorded on Tuesday, 7 October, with 75 customers. The number of customers being served ranged between 28 and 33. Overall, customer arrivals during non-peak hours were lower compared to peak hours, resulting in smoother service and shorter waiting times at the store.

Table 5 Queue characteristics value of single-server and multi-server

Location	Counter Type	Period	Arrival Rate, λ	Service Rate, μ	Waiting time in queue, W_q	Waiting time in system, W_s	Server Utilization, ρ
Convenience store 1	Single-Server	Peak hour	42.6	21.27	10.255	13.938	73
Convenience store 1	Single-Server	Non-peak hour	31.9	17.7	0.438	1.815	23.336
Convenience store 2	Multi-Server	Peak hour	107.7	82.4	0.83915	1.8167	36.82
Convenience store 2	Multi-Server	Non-peak hour	69	31	0.12	0.472	6.92

Table 5 showed the queue characteristics for Convenience Store 1 (single-server) and Convenience Store 2 (multi-server) during peak and non-peak hours. It included arrival rate, service rate, average waiting time in the queue (W_q), average time in the system (W_s), and server utilization.Convenience Store 1 had an arrival rate of 42.6 customers per hour and a service rate of 21.27 customers per hour during peak hours, resulting in high server utilization of 73% and a long average waiting time of 10.255 minutes. During non-peak hours, the arrival rate dropped to 31.9 customers per hour, the service rate was 17.7 customers per hour, and server utilization decreased to 23.34%, with a short average waiting time of 0.438 minutes.

Convenience Store 2 had an arrival rate of 107.7 customers per hour and a combined service rate of 82.4 customers per hour during peak hours. Server utilization was 36.82%, and the average waiting time was very short at 0.839 minutes. During non-peak hours, the arrival rate dropped to 69 customers per hour, the service rate slowed to 31 customers per hour, and server utilization was very low at 6.92%, with an average waiting time of only 0.12 minutes.

Overall, Convenience Store 1 can get congested during peak hours, while Convenience Store 2 handles high customer arrivals better, resulting in shorter waiting times and higher service efficiency.

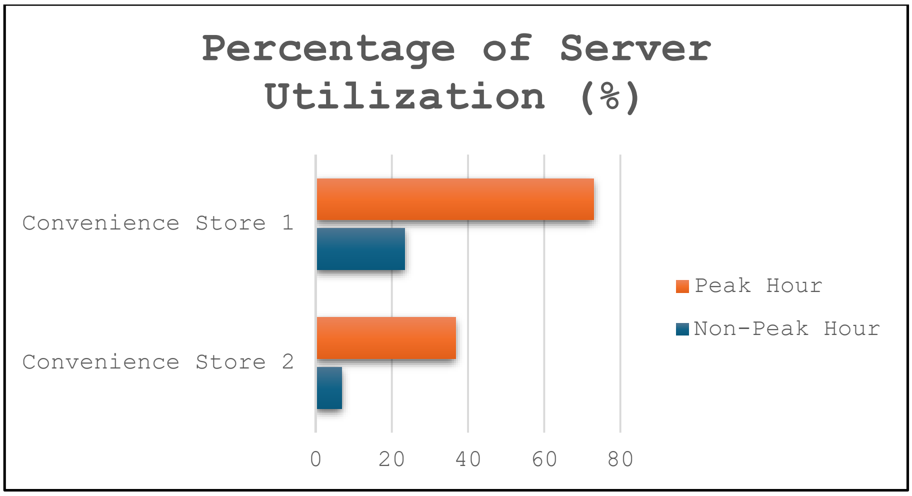

Fig. 1 Percentage of Server Utilization (%)

5. Conclusion

The analysis observations made over a period of ten days, distinct variations between system performance during peak and non-peak hours were identified. For instance, during the peak hours, the idle customers waiting to be served were many at the same time, leading to an increased waiting period, especially for the stores with fewer service counters. On the other hand, during the non-peak hours, fewer customers had to be served at the same period.

By comparing the results with waiting times at drive-thru fast-food restaurants using queuing models [6], it was observed that during peak hours (12:00 p.m. – 2:00 p.m.), server utilization was high, indicating that customer arrivals were elevated during this period, especially during lunch hour.

At Convenience Store 1, waiting times were noted during peak hours. The main reason for this was that the convenience store was near the market area, schools, and offices. Hence, many people visited during peak hours. The single-server system was unable to serve the many waiting customers in Store 1. The average waiting time was 10.255 minutes during peak hours, while it was 26.28 seconds during non-peak hours.

Meanwhile, at Convenience Store 2, customer arrivals were also high, especially on weekdays, due to its location near a school and residential area. However, Store 2 used a multi-server system, which allowed several customers to be served at the same time. As a result, waiting times were much shorter, with an average of 50.34 seconds during peak hours and 7.2 seconds during non-peak hours.

Overall, the results showed that multi-server systems performed better during peak hours by reducing waiting times and congestion. Adding more service counters, improving counter allocation, and using better queue management strategies can help reduce waiting times and improve customer satisfaction in convenience stores.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection****: Muhammad Haziq Nazmi Badrulzaman;* ***analysis and interpretation of results, draft manuscript preparation****: Muhammad Haziq Nazmi Badrulzaman, Norzuria Ibrahim. All authors reviewed the results and approved the final version of the manuscript.*

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